

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	01 Apr 96	Final 01 Dec 94 - 31 Dec 95	
4. TITLE AND SUBTITLE		5. FUNDING NUMBERS	
Characterization Equipment to Enhance Development of Group III Nitride			
6. AUTHOR(S)		61103D 3484/US	
Stephen D. Hersee, Associate Professor, EECE/CHTM			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)		8. PERFORMING ORGANIZATION	
The Regents of the University of New Mexico Center for High Technology Materials (CHTM) 125 EECE Building Albuquerque, NM 87131-6081		AFOSR-TR-96 6182	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		AGENCY REPORT NUMBER	
Air Force Office of Scientific Research/NE 110 Duncan Ave., Suite B-115 Bolling AFB, DC 20332-0001		F49620-95-1-0064	
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE	
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED			
13. ABSTRACT (Maximum 200 words)			
<p>This equipment has played a vital role in our development of wide-gap GaN and related AlInGaN alloy semiconductors that are rapidly finding application in optoelectronic and high temperature devices. In particular, the high resolution X-ray diffractometer has enabled us to understand how the thin, low-temperature buffer layer, that is grown before the main III-N epilayer, controls the crystallinity of the epitaxial film. The 244nm laser is being used as a pump laser for III-N materials and in combination with the XRD system is providing a rapid measure of alloy composition and crystal quality. These measurements are beginning to reveal important information concerning the stability of indium containing III-N alloys, that will have a major impact on heterostructure design.</p>			
14. SUBJECT TERMS		15. NUMBER OF PAGES	
Group III-Nitride		6	
17. SECURITY CLASSIFICATION OF REPORT		16. PRICE CODE	
UNCLASSIFIED			
18. SECURITY CLASSIFICATION OF THIS PAGE		19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED		UNCLASSIFIED	UL

## **DURIP-94**

**Characterization Equipment to Enhance Development  
of Group III-Nitride Wide Gap Semiconductors**

**Sponsoring Scientific Office: AFOSR/NE**

**Grant #: F49620-95-1-0064**

### **FINAL REPORT**

**APRIL 1996**

prepared by

Professor Stephen D. Hersee  
Centre for High Technology Materials  
University of New Mexico

The views and conclusions contained in this document are those of the author and should not be interpreted as representing the official policies, either expressed or implied, of the Air Force Office of Scientific Research or the U.S. Government.

## 1. Introduction

We are pleased to report that the equipment purchased under this DURIP contract is now installed and actively serving its intended purpose of providing advanced characterization of MOCVD grown GaN and related AlInGaN alloy, wide-bandgap semiconductors.

## 2. Philips High Resolution X-Ray Diffraction System

### 2.1 Buffer Layer Studies

This state of the art HRXRD instrument is being used to determine the microstructural properties of GaN and related semiconductor alloys. We have observed that the GaN nucleation or buffer material, that is deposited at low temperature (~500C), critically controls the crystalline, electrical and optical properties of the main III-N epilayers that are grown at higher temperature. The buffer material is often amorphous in its as deposited state but as the growth temperature is raised to 1050C the layer becomes polycrystalline. The high count rate and excellent resolution of the Philips XRD system has allowed us to track the evolution of this crystallinity even in buffer layers as thin as 200Å and figure 1 (lower figures) illustrates this transition to a polycrystalline state. AFM measurements on the same samples (upper images in figure 1) reveal that this buffer redistribution forms discrete growth islands that then act as nuclei for separate polycrystal grains during the higher temperature growth stage.

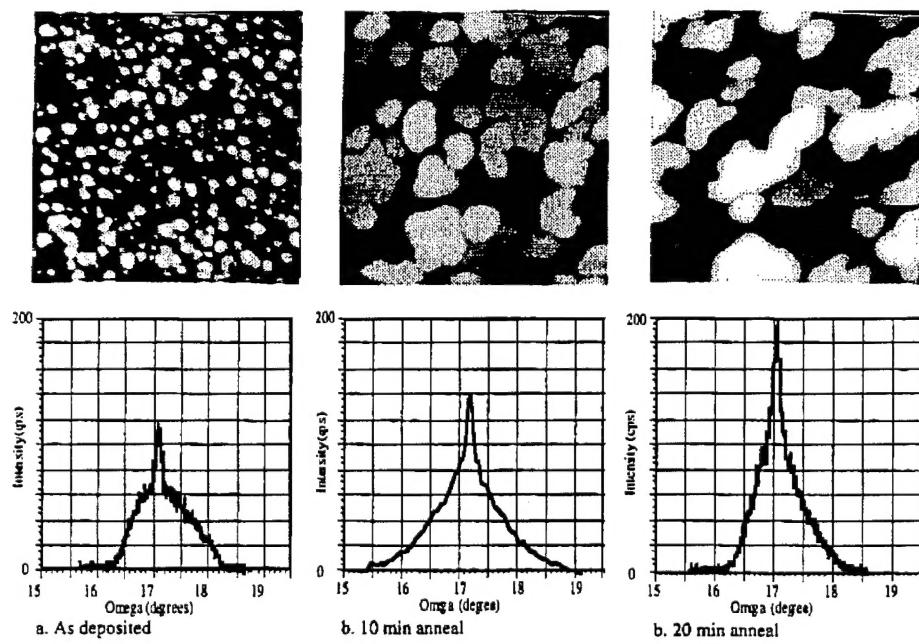


Figure 1: AFM and XRD data for GaN buffer layers on c-plane sapphire for different ramp anneal times. The AFM image area is 0.4 mm x 0.4 mm, with lighter regions corresponding to higher surface features.

The eventual crystalline state of the buffer and of the main epilayers grown on top the buffer, are critically controlled by the deposition conditions of the buffer and by the conditions used during the ramp to higher growth temperature.

## 2.2 InGaN XRD Studies

The advanced automation capabilities of the Philips instrument has allowed us to perform lengthy (~ 20 hours) Omega vs. Omega/2Theta 2D maps, on thin layers of GaN and InGaN, AlGaN alloys. These maps (see figure 4) reveal that inspite of the large lattice mismatch between GaN and the sapphire substrate, the residual strain in the III-N epilayers is small and comparable with that found in homoepitaxial growth (~ 30 arcseconds). However, these plots also reveal a large mosaicity (range of "c" axis directions) that confirms the polycrystalline nature of the III-N epilayers. The mosaicity remains approximately constant for different alloy compositions within a heterostructure, which confirms that the orientation of individual polycrystals is "set" at the buffer/substrate interface and is invariant after that.

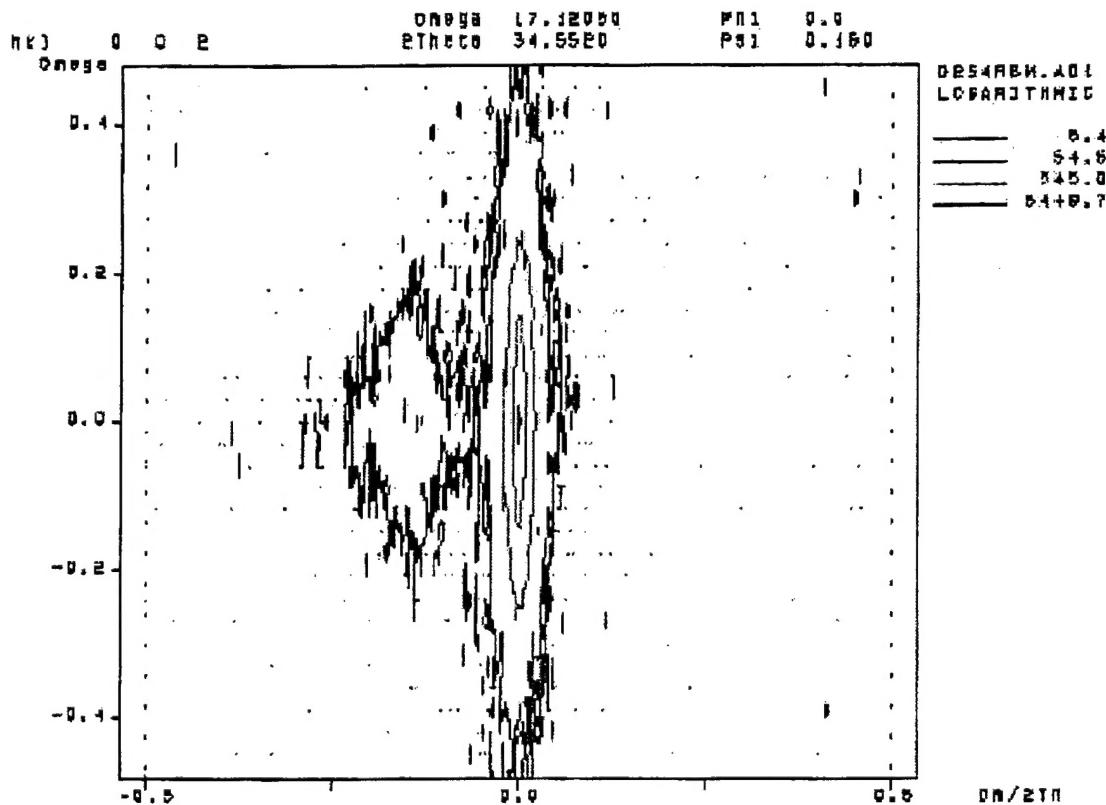


Figure 3. A reciprocal space map of an InGaN/GaN heterostructure. The vertical axis represents the Omega (rocking curve) measurement while the horizontal axis represents the Omega/2-Theta measurement. The vertical width of the peaks therefore reflects sample mosaicity while the horizontal axis reflects lattice strain.

**3. UV Photoluminescence System Built Around Coherent Inova FrED 244 nm Pump Laser**

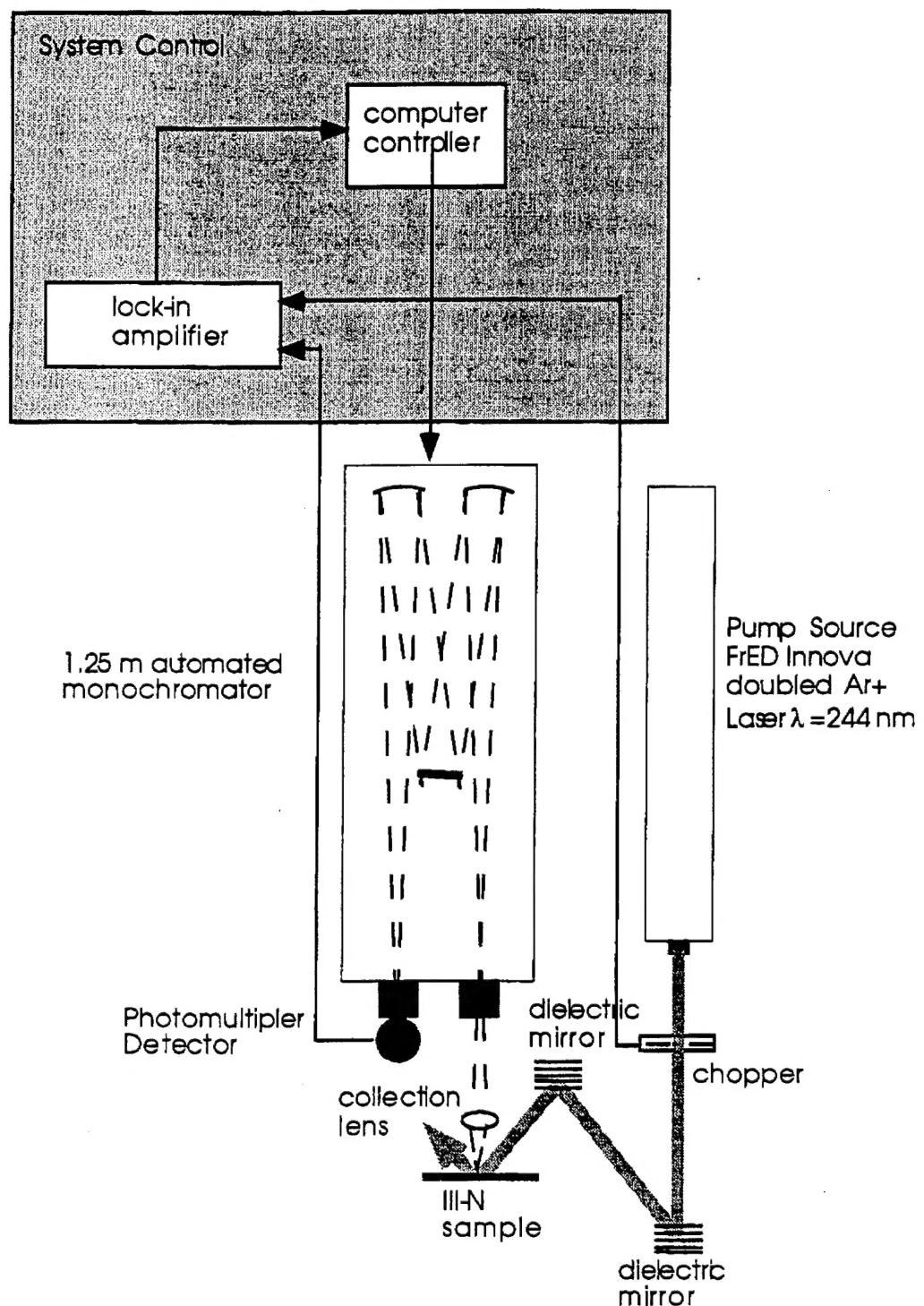


Figure 4. The III-N Photoluminescence System built around the FrED Innova double Argon 244 nm laser.

The Inova FrED 244 nm Pump Laser (Coherent Inc.) has now been fully integrated into the photoluminescence (PL) set up (figure 4.) This system allows rapid measurement of room temperature PL spectra as required for identification of alloy composition (figure 5) and III-N material quality. The PL measurement of bandgap and alloy composition is particularly useful for AlGaN alloys containing small mole fractions of AlN, which can not be determined by XRD measurements. (AlN and GaN are closely lattice matched so the X-ray peak separation is small. Mosaicity broadening of the XRD peaks makes XRD determination of AlGaN compositions in the <10% AlN mole fraction range very difficult.)

The absence of surface states in GaN and its related alloys allows useful PL measurements to be made on thin III-N layers. Furthermore, by using different pump wavelengths (which have different absorption lengths) we can obtain PL spectra from different depths within the sample and measure vertical composition uniformity.

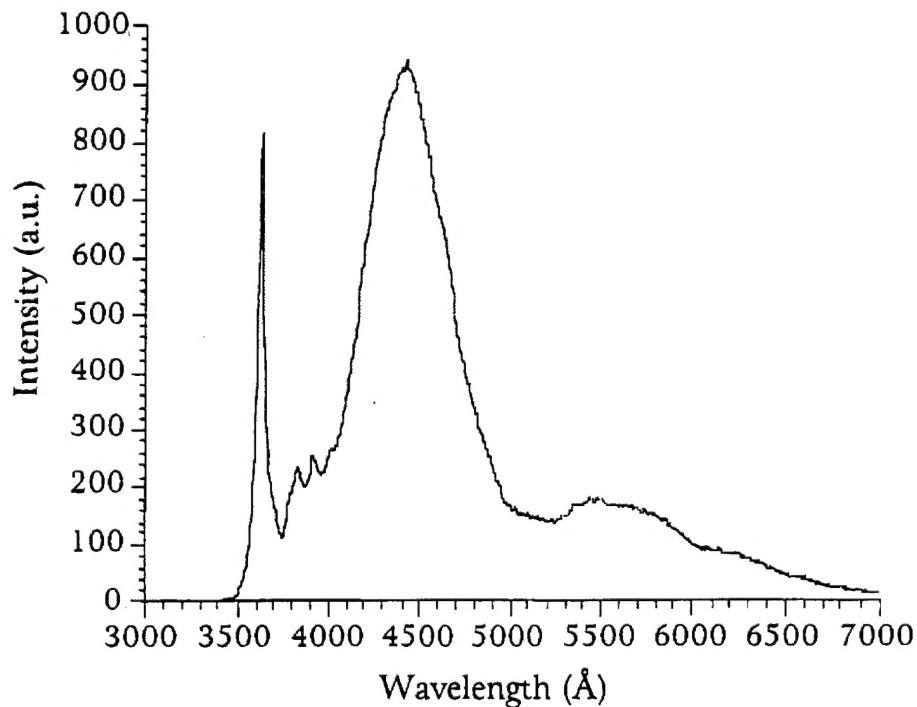


Fig. 5. A typical PL spectrum for an  $In_{0.22}Ga_{0.78}N/GaN$  heterostructure showing the sharp band edge peak for GaN at 365 nm and InGaN luminescence at 440 nm.

#### 4. Associated References

##### Publications

S.D.Hersee, J.Ramer\*, K. Zheng, C. Kranenberg, K. Malloy, M. Banas and M. Goorsky, "The Role of the Low Temperature Buffer Layer and Layer Thickness in the Optimization of OMVPE Growth of GaN on Sapphire", *J. Electronic Mats.* 24 (1995) 1519-1523.

J. Zolper, M. H. Crawford, A.J. Howard, J. Ramer\* and S. D. Hersee, "Morphology and Photoluminescence Improvements from High Temperature Rapid Thermal Annealing of GaN", *Applied Phys. Lett.*, 68 (1996) 200-202

L. Zhang, J. Ramer\*, J. Brown, K. Zheng, L.F. Lester and S.D. Hersee, "Electron Cyclotron Resonance Etching Characteristics of GaN in SiCl<sub>4</sub>/Ar", *Applied Phys. Lett.*, 68, 1996, 367-369

##### Reviewed Conference Presentations

S.D.Hersee, J.Ramer\*, K. Zheng, C. Kranenberg, K. Malloy, M. Banas and M. Goorsky, "The Role of the Low Temperature Buffer Layer and Layer Thickness in the Optimization of OMVPE Growth of GaN on Sapphire", presented at the 7th Biennial Workshop on OMVPE, Ft. Myers, Fla, April (1995).

S.D.Hersee, J.Ramer\*, K. Zheng, C. Kranenberg, K. Malloy, M. Banas, "Critical Parameters in the OMVPE Growth of High Quality GaN on Sapphire", presented at the 6th European Workshop on MOVPE and Related Growth Techniques, Gent, Belgium June 1995.

J.Ramer\*, K. Zheng, C. Kranenberg, K. Malloy, M. Banas and S.D.Hersee, "A Study of the Growth Parameters that Influence the Initial Stages of MOCVD Growth of GaN on Sapphire" presented at the First International Symposium on GaN and Related Materials at MRS Fall Meeting 26th Nov. 1995, Boston, MA

J. Zolper, M. H. Crawford, A.J. Howard, S.J. Pearson, C. Abernathy, C.B. Vartuli, C. Yuan, R. A. Stall, J. Ramer\*, S. D. Hersee, "Ion Implantation Doping and High Temperature Annealing of GaN", presented at First International Symposium on GaN and Related Materials at MRS Fall Meeting 26th Nov. 1995, Boston, MA

M. Banas, G. Liu, J. Ramer\*, K. Zheng, S.D. Hersee and K. Malloy, "Excitation Wavelength and Saturation Effects on GaN Photoluminescence", presented at First International Symposium on GaN and Related Materials at MRS Fall Meeting 26th Nov. 1995, Boston, MA